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MODEL EXPERIMENTS ON THE ACOUSTIC SIGNAL FROM AIRDROPPED MINES

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INTRODUCTION

Airdropped mine cases often give two or more distinct acoustic signals but no regularity has been found concerning the appearance and time intervals between the various signals. In the present paper model experiments have been undertaken to determine the origin of these acoustic pulses occurring after the pulse at impact. One may think of several sources for pulses occurring after impact: 1) reflections; 2) cavity closure; 3) a slap of the mine case against the wall of the entry cavity, due to whip, as suggested by J. H. Wayland. Reflections are easily eliminated or recognized in a tank of known geometry, but seem to be ruled out by the fact that subsequent signals are often as strong as or occasionally stronger than the impact signal. Therefore the experiments were designed primarily to distinguish between cavity closure and wall slap as possible sources of the acoustic signal. Accordingly simultaneous high speed motion pictures of the water entry of projectiles and their subsequent behaviour were taken together with acoustic records.

The projectiles used and the main results obtained with them are as follows:

1) One inch diameter steel spheres. These gave a signal only on impact; the closure does not give a signal of a level observable with the gain used.

2) A one inch diameter model of the Mark 36 mine:

a) With the original chamfered nose. This gave a strong impact signal, and later strong pulses, one of which coincides in time with the slap of the model into the cavity wall.

b) With a nose built up by hard wax, withthe purpose of modifying the hydrodynamic forces on the nose and therefore the subsequent motion of the model. This procedure modified the acoustic signal profoundly. In particular a conical nose gave only a weak entry signal and no subsequent pulse, obviously because the conical nose does not produce torque and subsequent slap.

c) In no case was a signal from closure observed.

The experiments were performed at N.O.L. where the tank, the air gun, and the photographic equipment used by McMillen and May in their photographic water entry studies were put at our disposal.

EXPERIMENTAL: PROCEDURE

The experimental arrangement is shown in Figure 1. A typical sequence of events for a firing is as follows:

a) The motion picture camera is started.

b) When the film speed has reached the desired value an automatic switch in the camera trips the relay which fires the air gun.

c) The projectile breaks two light beams having a known separation along the length of the gun barrel.

d) The pulses generated in c) are used to start and stop a Potter counter Model No. 450 and supply velocity data.

e) The pulse from the bottom photocell is fed into an amplifier and then a delay circuit having an adjustable delay time.

f) The delayed pulse trips the sweep on the oscilloscope and is timed to record any desired portion of the acoustic signal.

Many preliminary experiments were made without the motion picture camera in operation, and some experiments were modified as follows:

a) At times the entry signal pulse was used to trip the oscilloscope. This was the usual procedure when fast ($\sim$ 1 millisecond) sweep speeds were used.

b) For many experiments two acoustic records were made: one on a long sweep tripped by the amplified but undelayed entry pulse and the other on a fast sweep initiated by the same pulse after a time delay selected to coincide with an expected subsequent event.

c) When details of the acoustic pulse were not recorded on the fast time base the delay line was inserted as in Figure 1 with enough delay to allow the projectile to travel to just above the water surface. In such cases the sweep times were of the order of 50 msec. for the undelayed and 5 msec. for the delayed sweep.

Calibration: For nearly every experiment a calibrating trace, a sine wave of known frequency, was photographed on the sheet film since the spot displacement as a function of time was not linear. Since we were interested mostly in noises with amplitudes of the same order of magnitude as the impact noise, the voltage amplitude of the calibrating trace was not always recorded; this was done only for those experiments in which simultaneous optical and acoustic records were obtained.

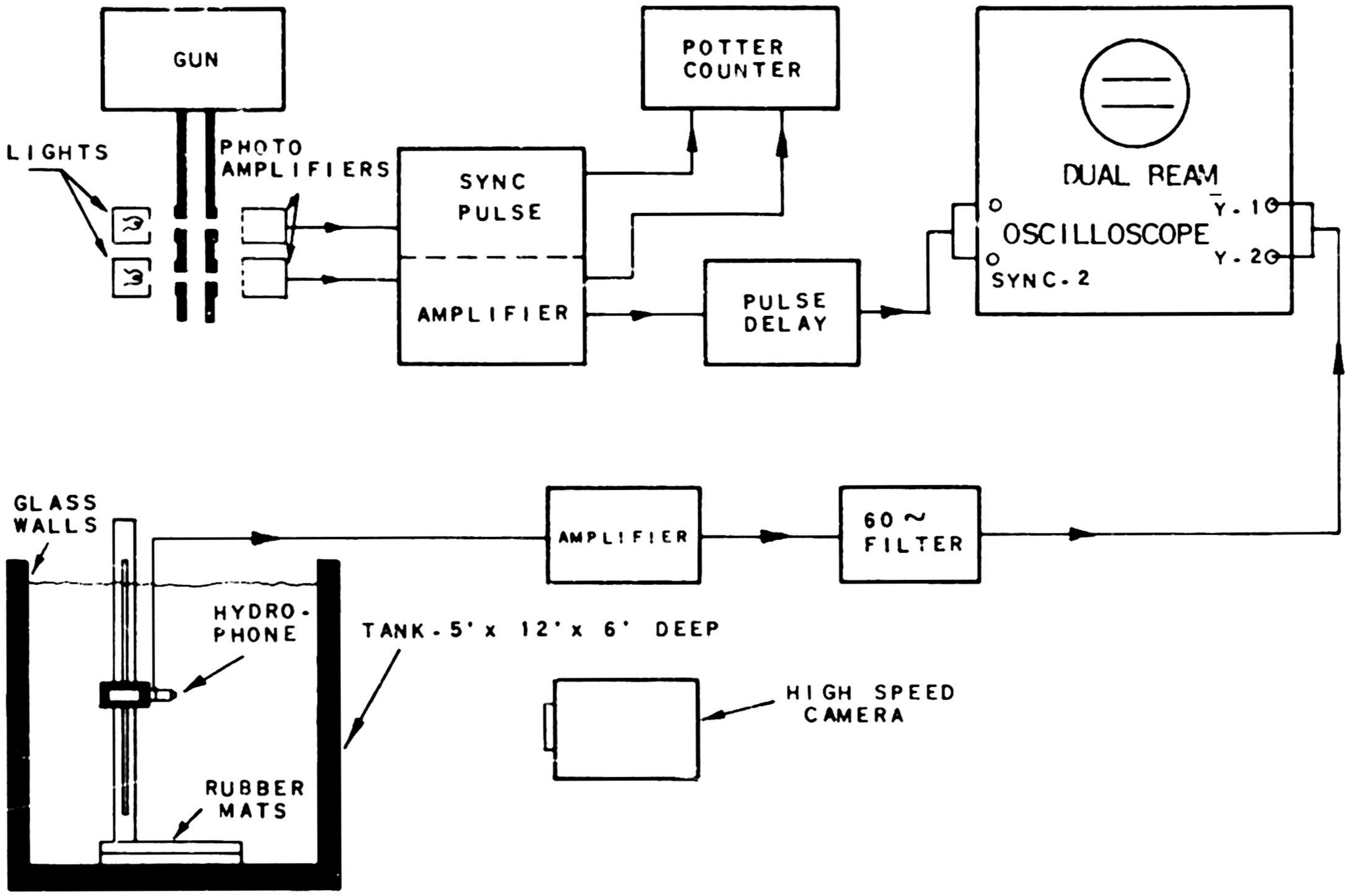

Figure 1. Experimental Arrangement.
The usual hydrophone position was in the plane normal to the paper at right angles to the position shown here.

EXPERIMENTAL: EQUIPMENT

Optical: The motion picture camera was the 16mm. High Speed Eastman Kodak Type 3, with an F 2.0 lens of 63mm. focal length. It was set to operate at about 1500 frames per second. The camera was focussed on a plane including the hydrophone.

At the far end of the tank a plate of ground glass in front of an array of 30 photo flood 1000 watt bulbs provided a bright background against which the details of the projectile water entry could be photographed with an f 5.6 aperature at 1500 frames per second.

The field of focus of the camera included a high speed clock. A rotating disc, driven by a synchronous motor, carried a vernier scale by means of which one millisecond markings on the rim could be interpolated to obtain 50 microsecond intervals. This was photographed on each frame of the film and provided a time scale for all optically recorded events.

Rolls of 50 feet of Super XX High Speed film were used in the camera; about 20 feet of this were used while the camera was accelerating to operating speed. All of the interesting phenomena (approach to water surface, water entry, cavity formation, wall slap, and cavity closure) were recorded on the next few feet of film. The camera is automatically stopped after the full roll has run through the camera.

Air Gun: The air gun has been used before at NOL.* In the present work it was operated at pressure of about 100 p.s.i., with projectile velocities of about 100 ft/sec. The projectiles were held in an aluminum sabot which was retained in the gun above the photocell windows. This eliminated the difficulty at first encountered when the air blast, leaking ahead of the projectiles, had occasionally caused spurious signals in the photocell circuits. The air chamber was charged manually to the required pressure; the charging valves were then closed and the gun was ready to be fired by the solenoid activated by the switch in the motion picture camera which is automatically closed when the camera attains operating speed.

Hydrophone: The acoustic detector was a barium titanate disc 2.5mm. thick and 12.7mm. in diameter. Its thickness resonance frequency is thus around one mc/sec. The disc was cemented directly to the flat end of an 0.75 inch brass rod 3.5 inches long which had on the other end a 2" brass collar which could be secured at any position along a 10 foot long slotted brass pipe shock mounted vertically in the tank. The shock mounting was effective in insulating the pickup from structure borne sound.

As usual, the best location for listening involved a compromise between intensity and interference. A position closer to the point of impact then 5" below and 5" horizontally from the vertical through the point of impact resulted in low frequency pressure variations, due to mass flow away from the cavity, and also in reflection interference from the water surface. Accordingly the hydrophone was located at a place 5" below and 7" removed from the point of impact. The axis of the hydrophone was located in the plane normal to the camera axis (see Figure 3) for reasons to be explained later.

Tests proved that in the absence of a missile no acoustic signal was obtained when the gun was fired, i.e., the presence of the sabot, which is stopped above the photocells, prevents any effect of the air blast.

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* D. Gilbarg and R. A. Anderson, Journ. Appl. Phys. 19, 439, 1948
A. May, ibid, 22, 1219, 1951

In early experiments a strong signal was produced by the missile striking the bottom of the tank. This was avoided by two layers of foam rubber.

Electronic Circuits: The photocell amplifiers and pulse delay (Phantastron) circuits were of conventional design; the rise time of the amplifier was less than one microsecond. Hewlett-Packard 450 A amplifiers were used in the acoustic channels; they are linear for frequencies as high as one mc/sec.

Oscilloscopes and Cameras: Two oscilloscopes were used, a Dumont Dual Beam No. 322 and the Dumont 304H. The latter was equipped with a Land Polaroid Camera and gave a quick record of the acoustic signals on a long time base. The camera used on the Dual Beam oscilloscope had an F 2.0 lens of 50mm. focal length. With fast speed cut film it permitted writing speeds of the order of 10^6 cm per sec.

Projectiles: In addition to the firings of the normal one inch diameter mine case model and the one inch diameter steel spheres, experiments were made for which the mine case was modified in various ways to change the normal acoustic signal pattern. These modifications are shown in Figure 2 in which all projectiles are drawn to scale as indicated. The thickness of the ends was approximately 6mm. except where the chamfer modifies this dimension.

For the mine case model with the chamfered nose the hydrodynamic forces on the nose result in a path curved away from the chamfer, with the slap on the cavity wall occurring on the side with the chamfer. (See Figure 3)

The projectiles were placed in the sabot in such a position that the curved path would lie in a plane normal to the camera axis and containing the transducer support.

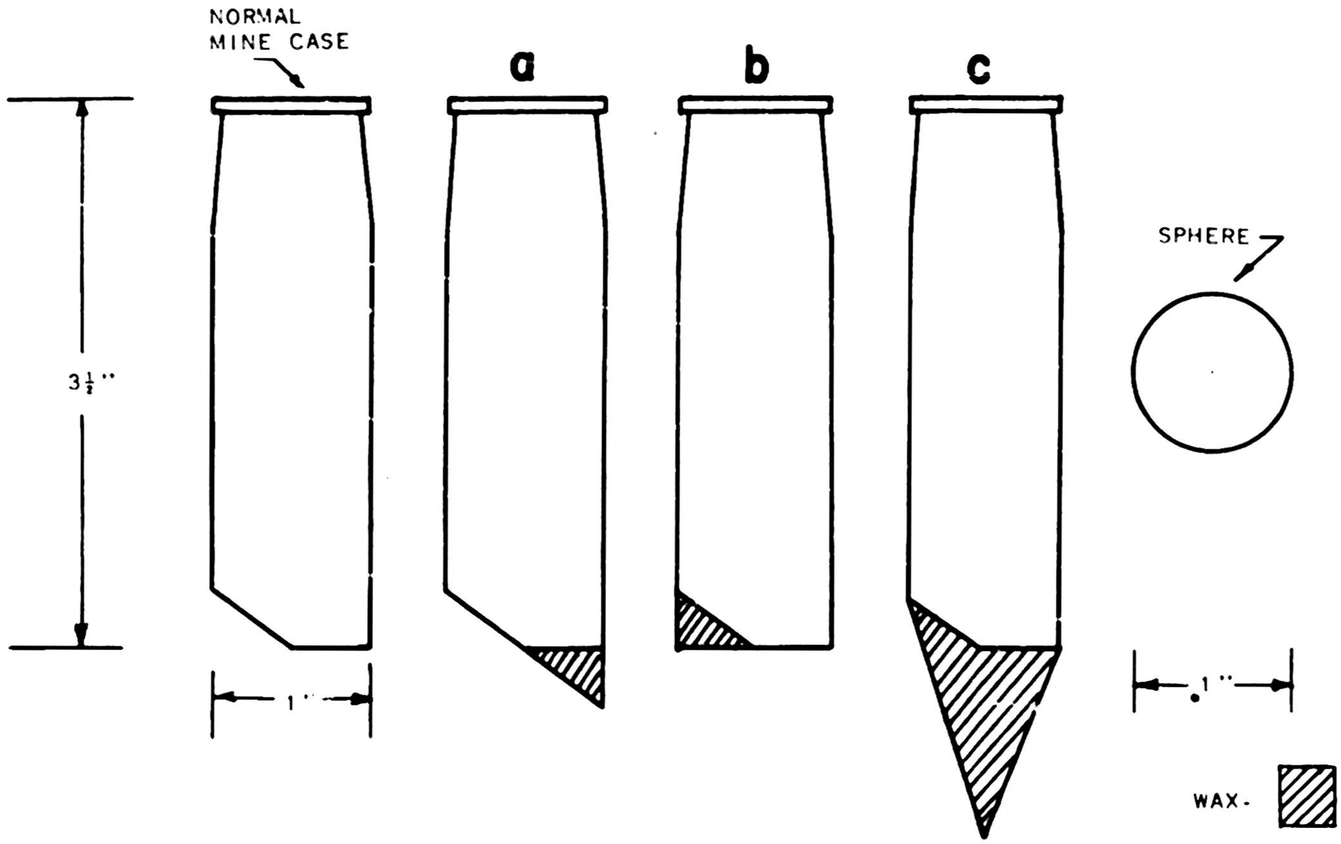

Figure 2. Projectiles.
Sphere was solid steel. Mine case was made of cylindrical aluminum tubing (wall thickness ~ 2 mm); it had a brass tubular insert (~3 mm wall); the ends were approximately 6 mm thick.

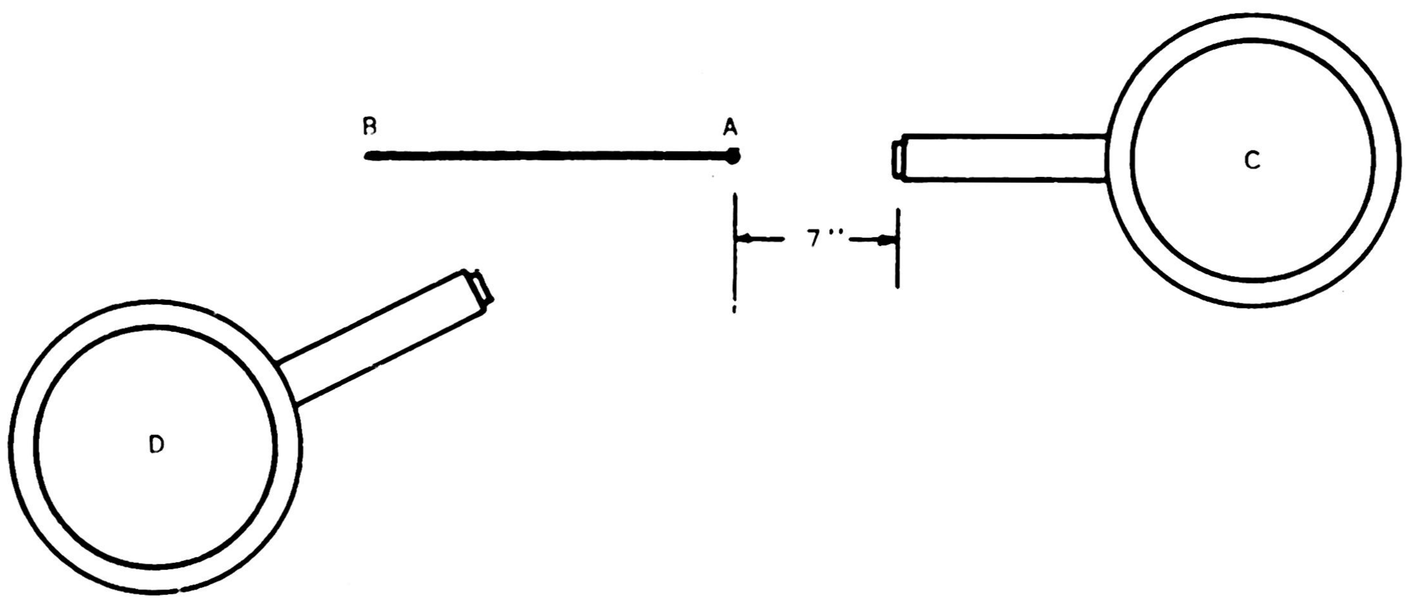

Figure 3. Hydrophone Position.
Top view; a, projection of point of impact; ab, projection of curved path of projectile; c, usual position of hydrophone; d, alternate hydrophone position.

RESULTS

The data obtained can be divided as follows:

A: Optical only: moving picture records only of the behaviour of missiles. Some of these were taken before the final synchronization of the electronic, acoustic, and optical equipment; others are the result of failure of some element in the electronic equipment. Most of the latter occurred when the impact noise was being used to trip the oscilloscope sweeps (Mine Case 17; Sphere 2).

B: Acoustic only: acoustic pressure as a function of time, with various speeds (Mine Case 51).

C: Simultaneous motion pictures and acoustic records (Mine Case 5; Sphere 2).

Spheres: The experiments with spheres can be briefly summarized. The impact noise is of the same order of magnitude as that produced by the mine case at impact; there is no trace of multiple acoustic signal having the same order of magnitude. In particular the motion pictures for sphere entry show a very reproducible cavity formation and closure, with closure between 13 and 15 milliseconds after entry.* There is no acoustic signal that can be distinguished, above the reverberation in the tank, at that time on the acoustic records. Figures 4 a and b are typical acoustic traces on which closure time, measured on moving picture film, is indicated. In Figure 4b the impact signal was used to trip the sweep so that only a small portion of tail of the impact pulse is written. The acoustic gain is somewhat more than that normally used, since the experiment was one in which we were looking for an acoustic signal at cavity closure.

Mine Case Model: chamfered nose

A: Moving picture record: Some sections of the moving picture records are shown in Figure 5. It turns out that the motion of the projectile after entry depends very much on the angle of entry (the angle between projectile axis and the normal to the water surface). In spite of great care this could not be controlled very well; only in about 50% of the shots was the entry vertical (angle less than 2°).

In vertical entry a cavity was formed 3 or 4 times wider than the projectile diameter. The mine case starts to turn slowly, right at entry, in the

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* See also A. May, Journ. Appl. Phys., 23, 1362, 1952

direction where the chamfer lies. The tail hits the cavity wall when the nose is about 6 or 7 inches below the surface, and about 6 to 9 milliseconds after impact. A little later, one sees the tail deforming the cavity wall. It is rather difficult to observe the exact time of contact of the tail with the wall if the rotation of the projectile is not in the plane of observation; i.e., normal to the camera axis. The event becomes clearly visible only later, when the tail has turned far enough so that its projection appears in the same line of vision as the outline of the cavity. However, one can occasionally see that the contact has occurred by the appearance of a streak on the cavity wall.

Less than a millisecond later, the whole side of the projectile touches the cavity wall (broadside slap).

Closure of the cavity occurs much later (13-20 milliseconds after entry) and is much less sharply defined than for the sphere.

If the angle of incidence of the projectile is larger, rotation may be slower or faster than for normal incidence. If the chamfer is toward the water surface (angle marked positive) rotation is faster. The first event after entry of the nose is that the rim at the back of the projectile hits the water surface after about 4 milliseconds. Next the tail of the projectile hits the cavity wall, but here, this is not always a separate event. The broadside slap occurs between 5 and 7 milliseconds after entry, (see 6A1, 12A7, 13A12, 13A13 in Table I), but there is one case where this time is 10 milliseconds (12A6).

If on the other hand the chamfer is away from the water surface, (angle negative) the rotation is slower than for vertical entry.

Here one finds again a contact of the rim at the back of the mine case with (and possibly breaking away from) the water surface at about 4 milliseconds (4 milliseconds is the time the projectile takes to travel its own length). The tail touches the cavity wall after 9 to 12 milliseconds; the broadside slap follows about 2 milliseconds later (12A8, 13A9, 13A10, 13A15).

Table I lists the firings for which a motion picture record was obtained. It gives the estimated angle of entry, a positive sign signifying clockwise rotation as seen from the camera. Since in fitting the projectiles to the sabot the chamfer was always mounted toward the hydrophone, a positive sign means that the chamfer is oriented towards the water surface. The times, in milliseconds, at which the different events occur are counted from the moment of entry.

B) Acoustic Records

In nearly all acoustic records there occur besides the impact pulse others of the same order of magnitude.* Table II is an analysis of the acoustic records for 51 mine case firings. Times are measured from the beginning of the water entry pulse; amplitudes are given as grid dimensions on the screen covering the front of the oscilloscope tube. The gain was roughly the same for all firings.

It is seen that most firings contain at least one signal as large or larger than the impact signal. This occurs most frequently between 6 and 8 milliseconds, but may occur considerably later. It is often preceeded or followed at short distance by another pulse. Figure 6a and 6b show such a case. The first of these two signals may be interpreted as due to the tail hitting the cavity wall (see Table I); this is marked on Figure 6 by R. The second signal is interpreted as due to the broadside slap, and is marked S. In addition Table II shows often appreciable signals around 4 milliseconds, which may be interpreted as due to the rim hitting the water surface on oblique entry. When this is observed it is called Rs. The acoustic records occasionally show definite pulses in addition to the ones described above, whichwe cannot explain.

Table III repeats data from Tables I and II for the six cases where we have both optical and sound records. Acoustic signals of intensity 1 have been omitted, 1-2 are called weak (w), 2-4 moderate (m), above 4 strong (s). Obvious reflections are omitted. Table III shows that acoustic and optical records agree quite well for the times the tail hits the cavity wall and the broadside slap. Actually in that interval (8-10 milliseconds) the two signals are always present and no others. Sometimes the first is stronger, sometimes the second. There is repeatedly a weak to moderate signal around 4-5 milliseconds. In one case (12A5) this corresponds to the time the rim touches the water surface. It is possible that this occurs also in the other cases without showing up on the motion picture films, or it is possible that this is double reflection (2 x 2 milliseconds). Finally, there are occasionally unexplained signals after 10 milliseconds.

C) Effect of Hydrophone Position

The hydrophone receiving face was always vertical. However, it is still possible to rotate the axis of the hydrophone in a horizontal plane around the line of impact. As is shown in Figure 6c the entry noise is the same on both

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* In addition there are weak signals which are due to reflections from the tank walls; they follow at 2 millisecond intervals, and are included in the Table.

hydrophones. However, the second signal, received strongly by the hydrophone in the normal, or usual, position (upper trace) is absent from the hydrophone in the alternate position (lower trace). This may be interpreted in the following manner. In the normal position the hydrophone is on that side of the cavity on which the slap occurs. In the alternate position the air filled cavity lies between the hydrophone and the place of slap, and thus shields the hydrophone from the slap signal.

This experiment has two consequences: It is a further confirmation of our interpretation of the second signal as due to slap; and it gives one possible explanation of the apparent impredictability of the second signal in full scale tests.

TABLE I

MOVING PICTURE RECORD

Time in milliseconds after entry

Shot	Entry degrees	Rs time	R time	S time
11A4*	0		6.2	7.0
13A14	0		7.4	7.7
11A1	0		8.1	8.8
11A2	0		7.5	8.3
13A11	0		9.0	9.8
12A5++		4.5		8.3
13A12	+5	3.9	5.4	7.0
13A13	+10	3.8		5.4
12A6	+ 3		7.7	10.0
12A7	+ 7	3.8		5.2
13A16	+ 5	3.0		5.1
6A1*	+ 5			6.2
13A15*	-20	4.0		≈17.0
12A8	-3		9.6	10.4
13A10	-5	4.6	10.6	12.0
13A9	-5	4.5	12.1	13.6
7A2	0			7.5

Entry angle is estimated as clockwise deviation from vertical; Rs is time at which rim on tail strikes the horizontal water surface; R is time at which tail contacts cavity wall; S is time at which projectile is in broadside contact with cavity wall. Time in milliseconds is measured from instant of water impact.

* Film overexposed; accurate timing difficult.

++ Curvature of path not at right angles to camera axis.

TABLE II

ACOUSTIC RECORD--RELATIVE INTENSITY

Time in Milliseconds after entry	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Shot No.																				
15A1a	6								2											
15A1b	6				4									5						
15A1c	5				4		2													
15A2b	7		3		3	3	3	6				3		3						
15A2c	6		3		3		3			5		2								
15A3b	6		3		3	4														
15A3c	5		2			3½		3												
15A4b	3		2					2												
15A4c	7		2		2	2		5						2						
15A5a	5		2	3			5													
15A5c	4		2		2	2½		2		2		1								
15A6a	5		2			3½		2					2							
15A6b	3		1				1½	2				2								
15A6c	3		1½		1½	2		2		2½					1½	2				
7A1	4		3				1½													
7A2	2½				2	3½			1½											
7A3	5		2			4														
7A4	4½		3				2				3					4			5	
8A5	4		1½		2		2			3½			2½		2		2			
8A4	5		6																	
12A4	5			1		1		2	2½	4										
12A6	3½		1			1			2½		1	1								
12A8	3				2				3½		2									
12A9	3		1		3															
12A10	4		1		3							2								
12A11	7		3		4	6		4												
12A12	6		4																	
12A13	3½		1					2½	6½		2							1½		
12A14	3		1	1	½	3					1½			6				1		
12A15	4½		1	1				3			5		4							
12A16	8		1½		3															
12A17	2			2½				1	6								1			
12A18	4		2				2													
12A20	6		1½		1	1		1												
12A20b	5		1½		1	1½		1												
12A21	6		1½		1½	1½		1½												
12A23	12		3½		3		3½		4											
12A24	1	3	5		2		1½		1	1										
12A25	6		2		2	2			2½											
11A1	1								1		2½		7		3		2½		2	
11A2	7					2		3½		2½										
13A3a	1½		1½			8	2							3				2		
13A3b	5		2		2		3½		3		2									
13A3c	3				3½	3½			1											
13A4	6		1½		1½	1½		2½		3										
13A6	3			3½				2	3½											
13A1	2						3						2		2					
13A7	2½			3		5½			2											
13A5	9		3	3	3		2½													
8A6	3		1	1½				2			1½									
12A5	3½		1			1			2½		1	1								

Analysis of 50 shots of the mine case. The numbers indicate the height of the signals in terms of the size of the squares that appear on the photographs.

TABLE III

COMPARISON OF OPTICAL AND ACOUSTIC RECORDS

Time in milliseconds after entry

Shot	Entry angle degrees	Record: O: optical A: acoustic	Rs Rim hits surface	R Tail hits cavity wall	S Broadside slap
11A1	0	Optical		8	9
		Acoustic*		8w	10m, 12s
11A2	0	O		7.5	8.5
		A	5m	7m	9m
12A5++	0	O	4.5		8.5
		A	5w		8m, 10w, 11w
7A2	0	O			7.5
		A	4w, 5w		8w
12A6	+3	O		7.5	10
		A	5w	8m	10w, 11w
12A8	-3	O		9	10.5
		A	4w	8m	10w

All times have been given only to the nearest half millisecond; this is approximately the revolving time for the motion picture film.

* This record contains a series of acoustic signals after 12 milliseconds.
++ Curvature of projectile path not perpendicular to camera axis.

The Modified Mine Case Model.

Experiments were made to determine the effect of the shape of the nose of the mine case model. The modifications were made by adding hard wax as shown in Figure 2. The modified nose was not injured by water entry and could be used for repeated shots. Acoustic records d, e, and f of Figure 6 are typical for modifications a, b, and c of Figure 2 respectively. The non-symmetrical taper with pointed nose reduces water impact signal and increases the slap signal. With the flat nose the impact signal is stronger and longer, but there is no detectable slap. The symmetrically conical nose gives little impact signal and no slap signal that can be detected while using the same gain as in the preceding experiments. Obviously, with the conical nose there is no torque producing rotation of the mine case. The low frequency (around 70 cycles per second) displacement of the base line in such shots is similar to that obtained when the hydrophone is near the point of entry, and may be due to oscillations of a somewhat larger cavity formed by such a projectile. Figure 6f contains the acoustic records of such a shot.

Projectile Velocity:

A series of shots were made in which the entry velocity was varied by using air pressures in the gun ranging from 60 to 100 p.s.i. The acoustic traces showed little or no correlation between amplitude of impact signal and projectile velocity. This is probably due to difficulty of obtaining reproducible angles at entry between the flat portion of the nose and the water surface.

Pulse Detail:

In full scale experiments the signals from mine drops appear not as shock waves but show some periodicity. The question arose as to the origin of this periodicity, which could conceivably represent either oscillations of the cavity—the size of which is unknown in full scale experiments—or shock-excited oscillations of the mine case. For that reason it seemed useful to investigate the signals in the model case more closely.

In order to resolve the details of the signal at entry and slap fast sweeps were used. For the entry signal the sweep was triggered by the fast rising pulse front. Figure 4b shows such an expanded trace for a sphere, and Figure 7a for a normal mine case. In order to catch the details of mine case slap the signal at entry was used to trip the sweeps of the dual beam oscilloscope; the slow sweep was triggered without delay; the fast sweep was tripped after a 6 millisecond delay, the average time for the appearance of the slap signal. The record (if any) on the fast sweep can thus be identified by reference to that on the slower sweep. The record for a slap obtained in this manner is shown in Figure 7b.

For comparison with the above records photographs were made of the acoustic signals produced by tapping the mine case, suspended in the water, on the nose with a wooden rod to simulate entry and on the side near the tail to simulate slap. For these experiments the barium titanate disc was cemented to the mine case: when the nose was tapped the pickup was cemented to the flat portion of the nose; when the side was tapped the pickup was cemented to the side of the mine case model. Figure 7c and 7d were made in this manner. Traces were made for different depths of immersion of the mine case: just touching the water, half-immersed, and fully immersed at two different depths.

The cavities in our case have radii of at least 2 inches. If one treats them provisionally as spheres and assumes the pressure inside to be one atmosphere the fundamental would be at 150 cycles, and lower if the gas pressure were lower or the cavity larger.

The expanded sweeps show: for the sphere (Figure 4b) prominent frequencies near 36,000, with considerable harmonic content; for the entry signal of the mine case (Figure 7a) a prominent frequency at 50,000 and higher* harmonics. This falls off to 1/e after about 200 microsecond; after about 800 microseconds a prominent frequency of about 21,000 appears, with higher harmonics. However this is probably mixed in earlier. For the slap a prominent frequency of 17,000 is visible, with appreciable harmonic content (Figure 7b). This signal* falls to 1/e in about 210 microseconds (Q about 11).

These results exclude bubble oscillations as source. Higher bubble modes have higher frequencies but should be less intense.

The mine case fully immersed in water and tapped at the end produced a prominent frequency at 21,000 cycles with appreciable fourth harmonic at the earlier stages (pearly structure of the trace). A rough theoretical estimate, assuming a sound velocity in aluminum of 5.3×10^5 cm/sec and a half wavelength equal to the length of the model would give a frequency of 30,000 cycles.

When the fully immersed mine case was tapped on the side, the record showed a fairly simple damped frequency of about 17,000 with indications of the 3rd, 4th, and 5th harmonic. The different stages of immersion seemed mainly to shift the relative prominence of the different harmonics.

No frequency analysis has been carried out; the frequencies were measured on the prints by comparison, with a ruler, with the calibrating trace. In spite of this crude method of analysis it seems clear that the periodicity of the acoustic signal is determined by mine case vibration. The water entry signal contains, after 800 microseconds a frequency of 21,000, the same as that excited by end tapping; the slap contains a frequency of 17,000, the same as that excited by tapping the minecase on the side. The duration of the signal is determined by the damping of the mine case vibration. The signal from the

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* If this is due to a higher mode of vibration of the case, it might contribute relatively less to the signal at larger distances.

sphere lasts somewhat longer than that from the Mark 36 mine case model; this means that the solid steel sphere is less damped than the hollow model.

Actually we are not sure, either from the theoretical or experimental standpoint, whether the acoustic signal does start with a real shock wave or not. It is however certain that the rest of the signal is due to a shock-excited vibration of the model which is transmitted to the water. An argument for the absence of a shock wave can be made from the recordings of full scale tests, where the signal seems to start directly with the vibrations. Of course in the full scale mine the case oscillations will have much lower frequencies than in the model. To test our interpretation one should measure the acoustic or vibration frequencies of the different mines. If a systematic study is made it might e.g. be possible to distinguish steel and plastic cases when airdropped.

Conclusions

The experiments described here support the following conclusions concerning acoustic signals from airdropped mines.

1. The first signal is due to the nose entering the water.

2. Subsequent signals are produced by the tail touching the water (in the case of oblique entry) and by the slap of the tail of the mine case against the cavity wall.

3. Closure of the cavity does not produce a comparable signal, at least above 100 cycles.

4. The acoustic intensity is probably more dependent on the details of the impact than upon velocity.

5. At least a good part, and perhaps all, of the acoustic signal is due to shock excited vibrations of the mine case which are transmitted to the water.

Conclusions similar to 2 and 3 have also been reached* by H. Wolfe and T. Kinage.

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* H. Wolfe and T. Kinage, NOTS—TM660; dated July 22, 1952

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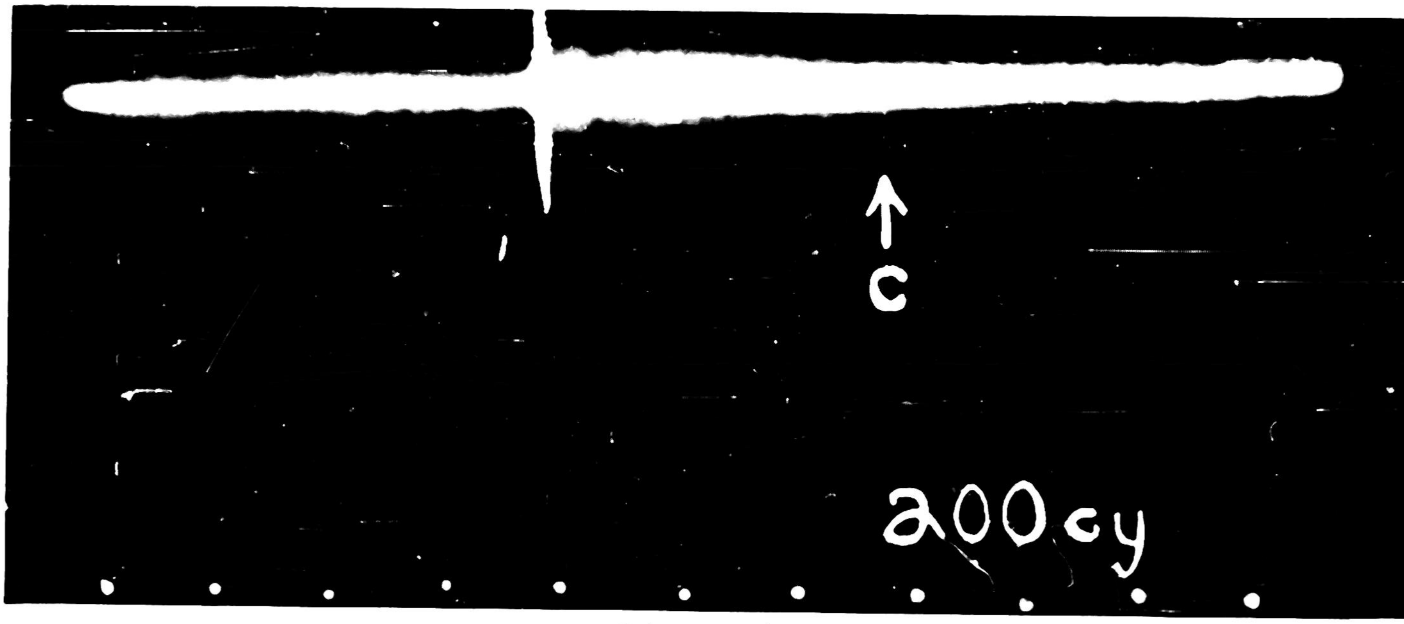

Figure 4a

Acoustic record for sphere; "C" is closure time from motion picture films.

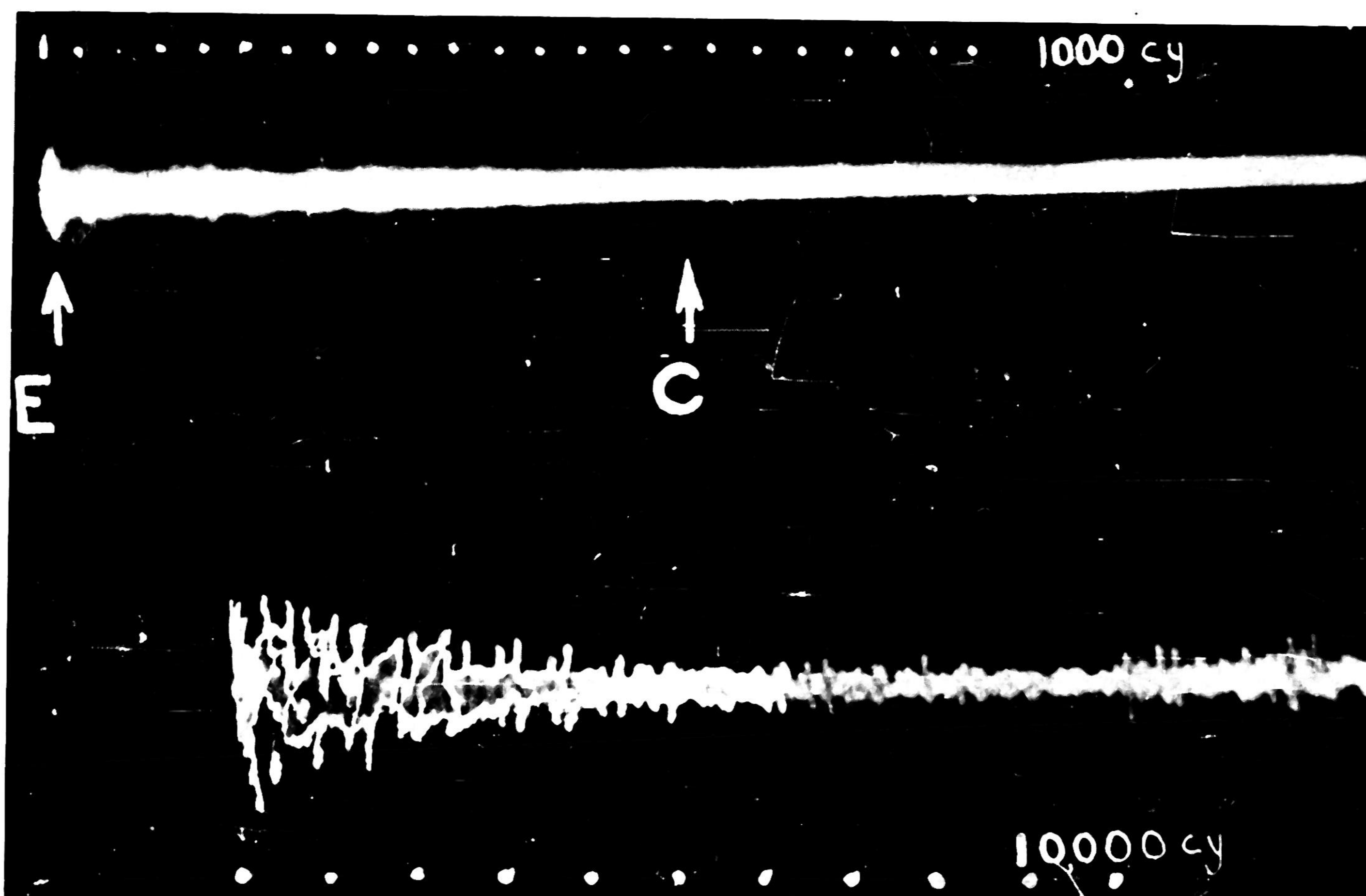

Figure 4b

Acoustic record for sphere; closure time as measured on motion picture film is indicated on the slow sweep; details of entry noise are given on fast sweep.

Figures 5a, b, c, d, e, f
Selected motion picture frames showing typical water entry phenomena for normal mine case. Smallest division on clock rim is 0.5 milliseconds; vernier division corresponds to 0.05 milliseconds.

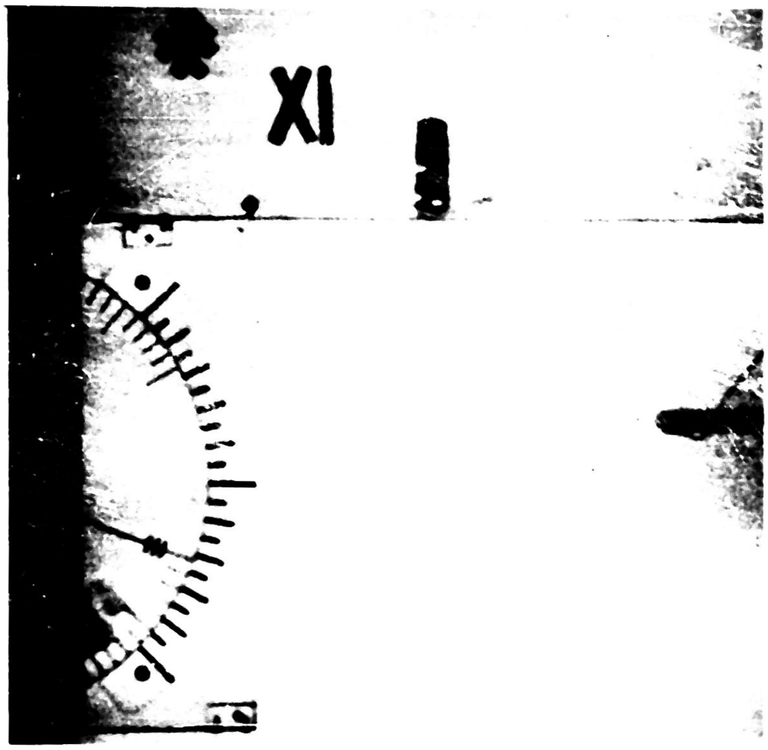

Figure 5a. Frame 1

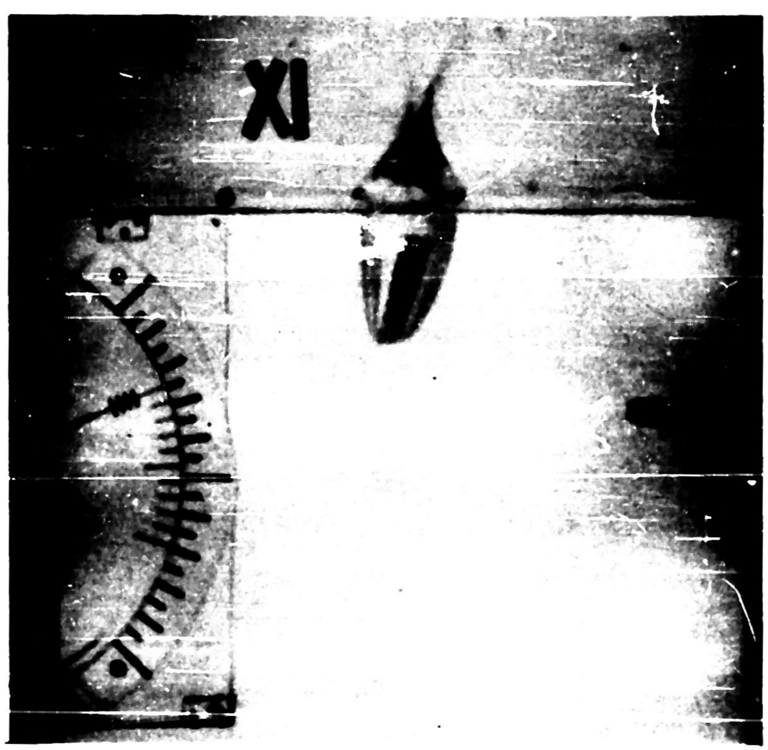

Figure 5b. Frame 8

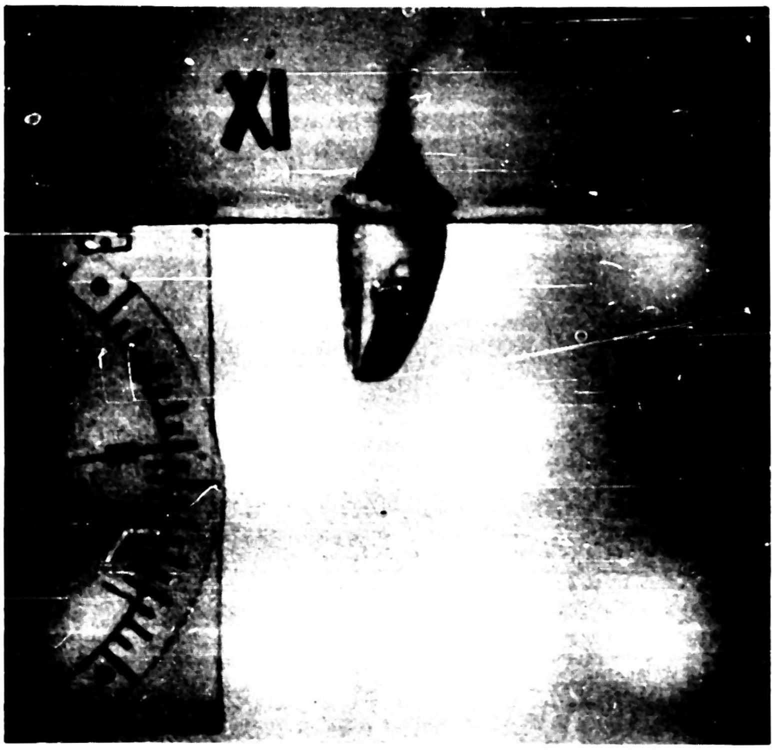

Figure 5c. Frame 10

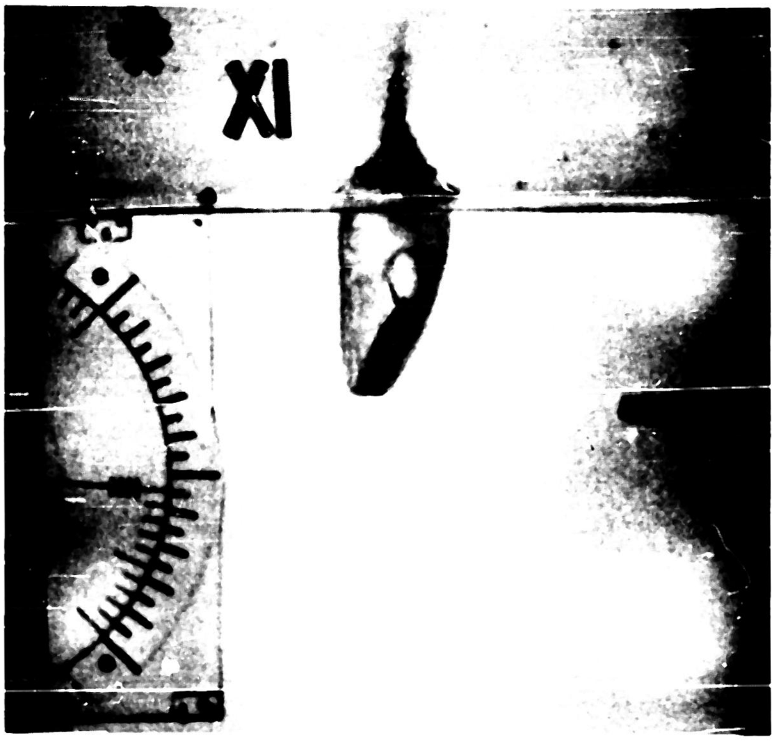

Figure 5d. Frame 12

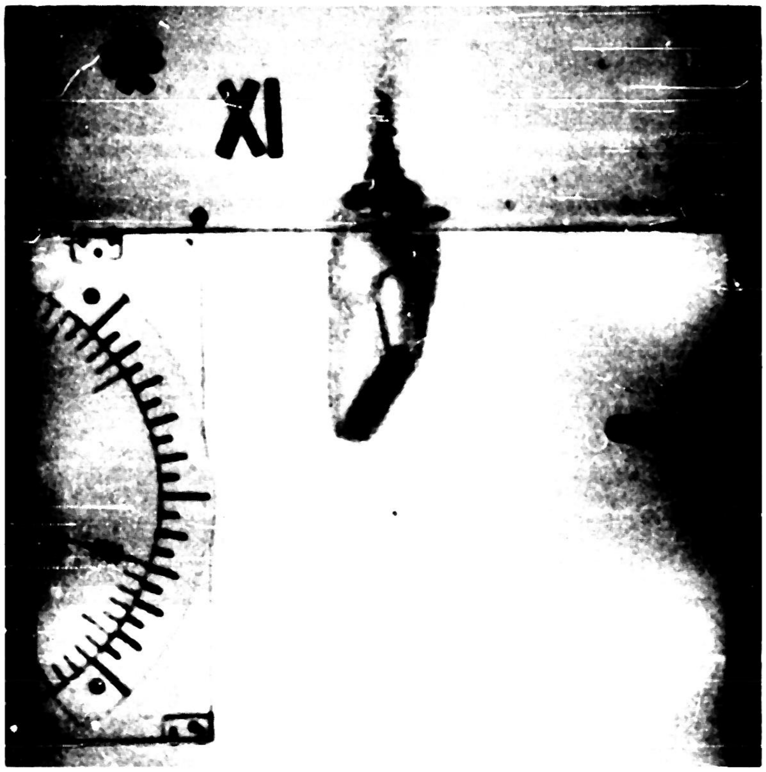

Figure 5e. Frame 19

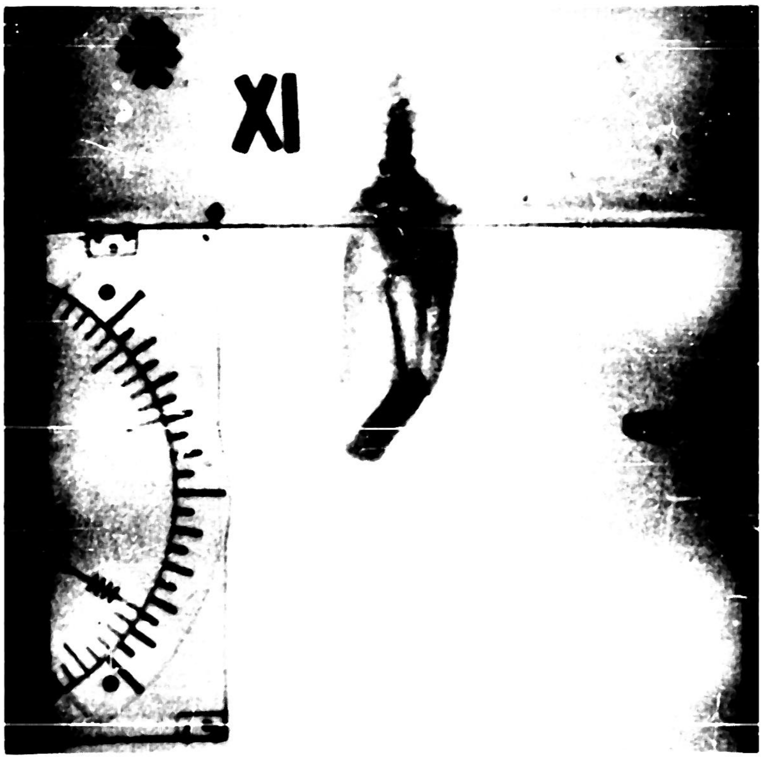

Figure 5f. Frame 16

Figures 6a, b, c, d, e, f

Acoustic records. Times from motion picture films are indicated on these records as follows: E entry; R time at which projectile tail hits cavity wall; S time at which projectile slaps broadside against cavity wall; C time of cavity closure.

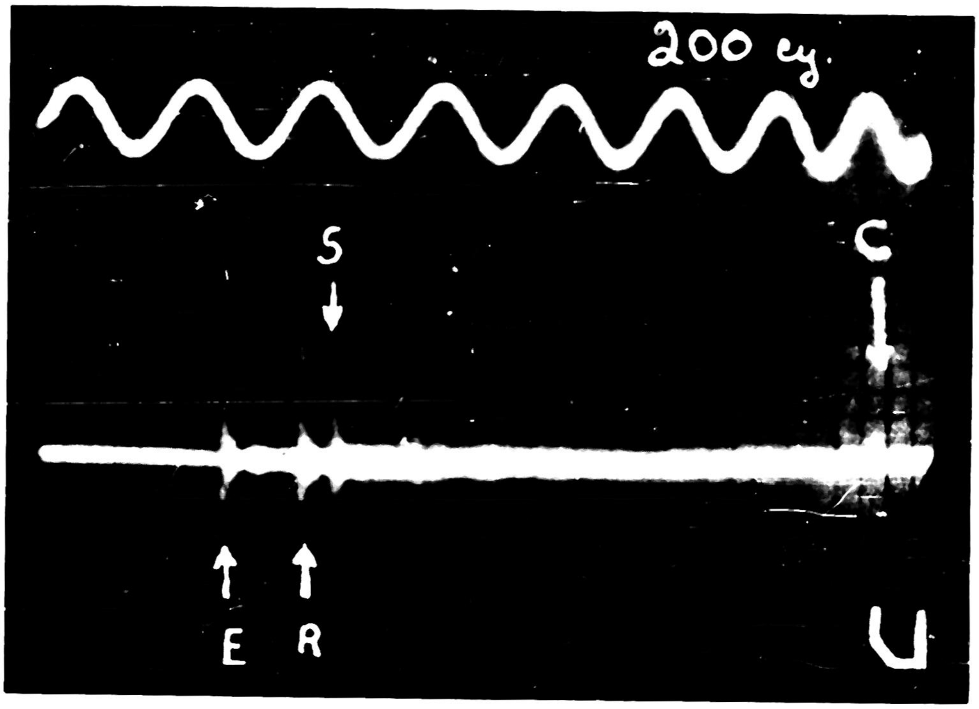

Figure 6a. Normal mine case

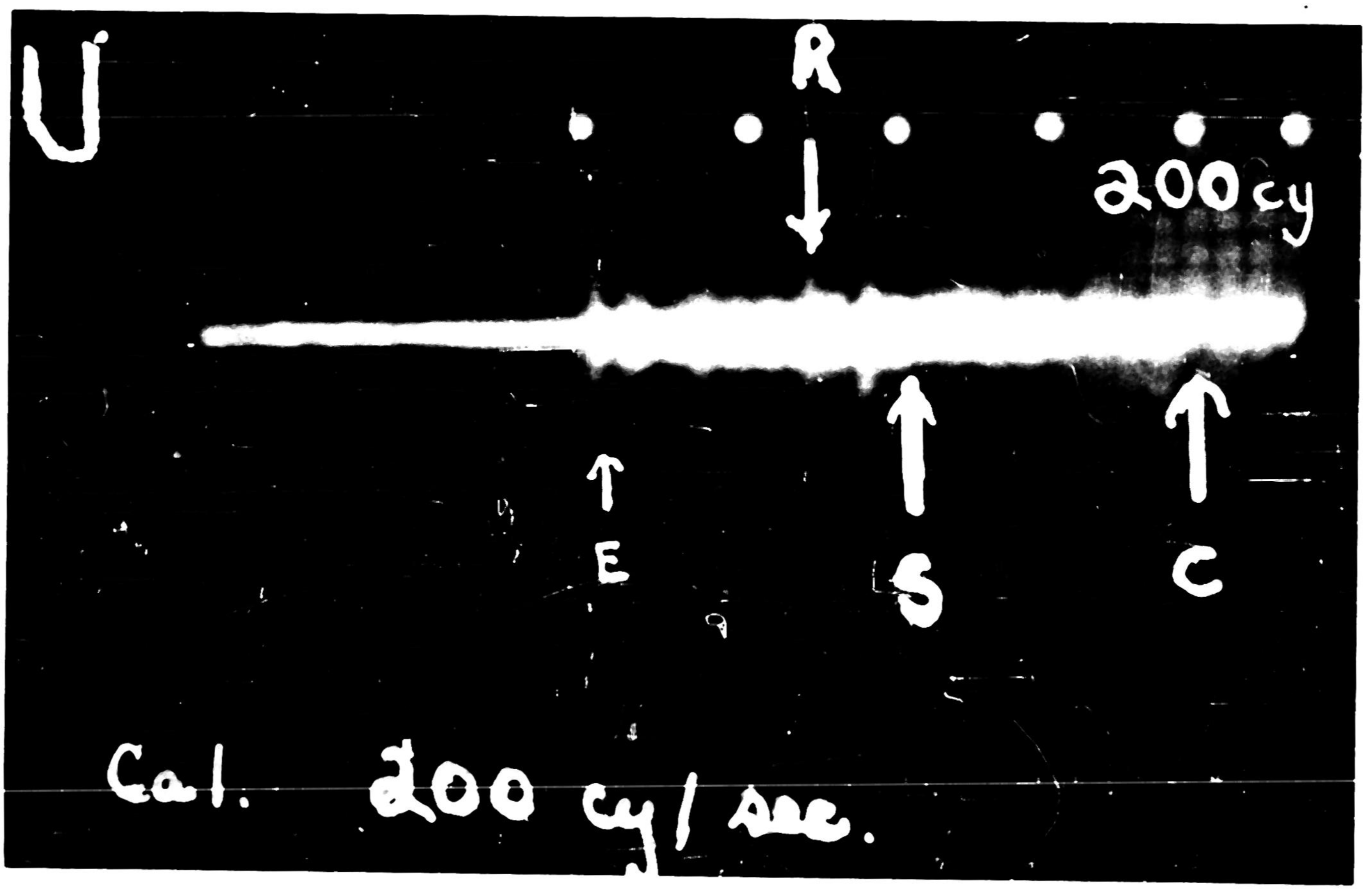

Figure 6b. Normal mine case

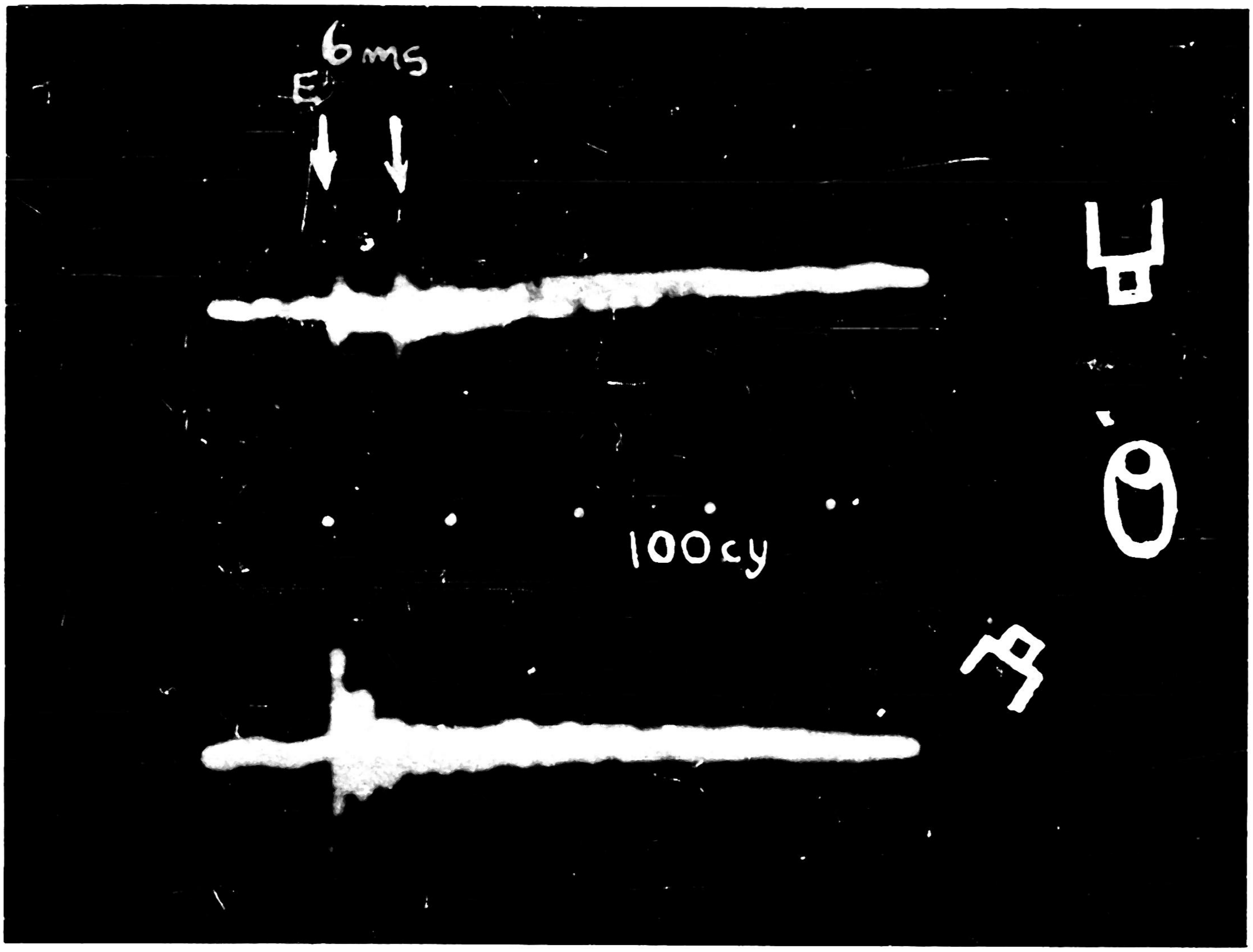

Figure 6c. Effect of hydrophone positon

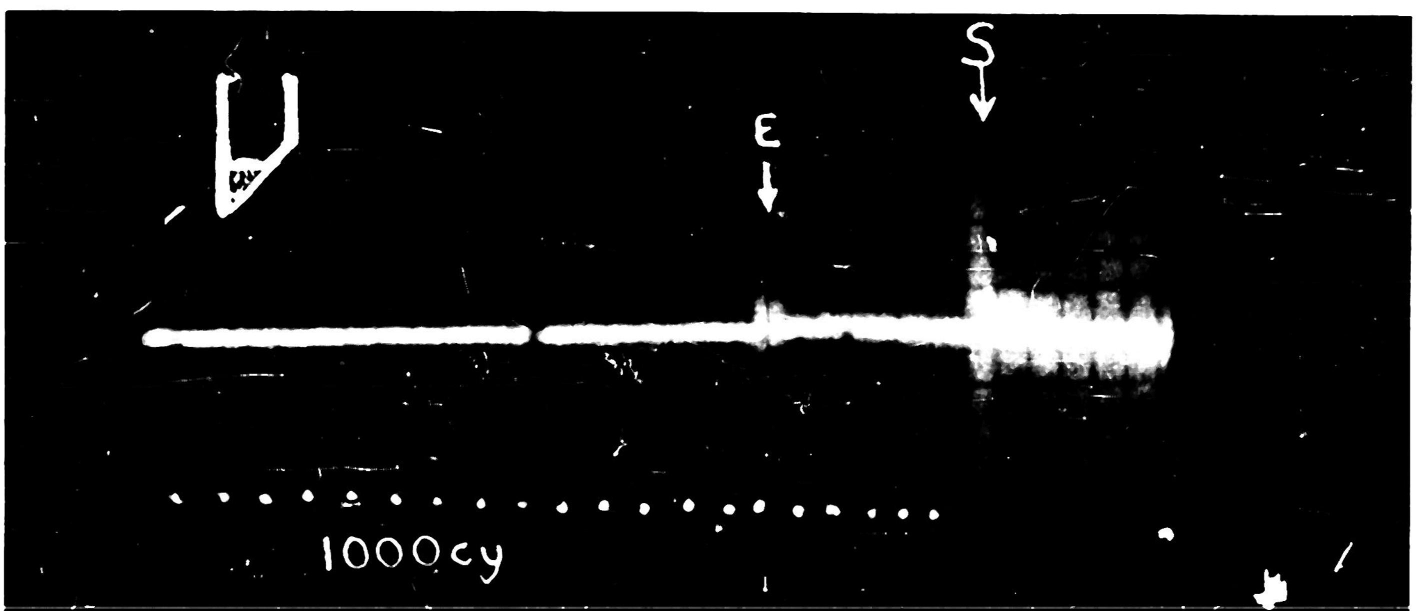

Figure 6d. Modified mine case nose

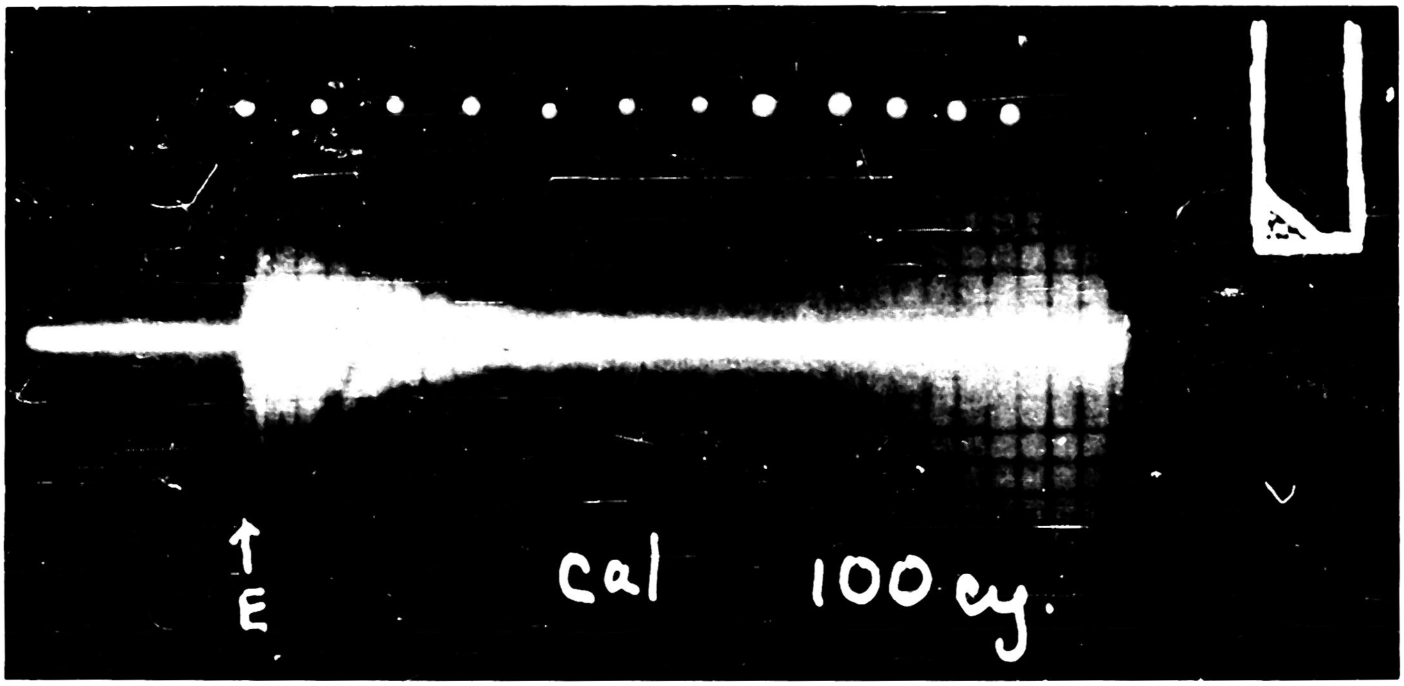

Figure 6e. Modified mine case nose

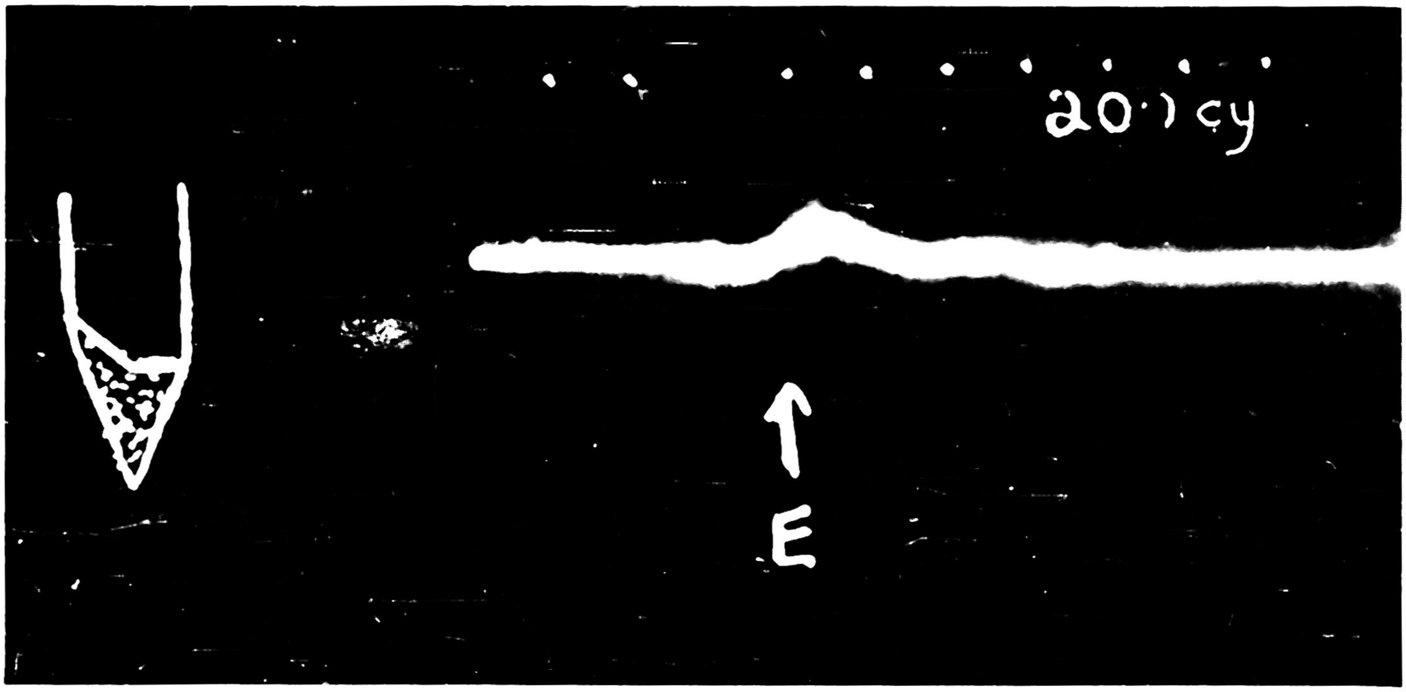

Figure 6f. Modified mine case nose

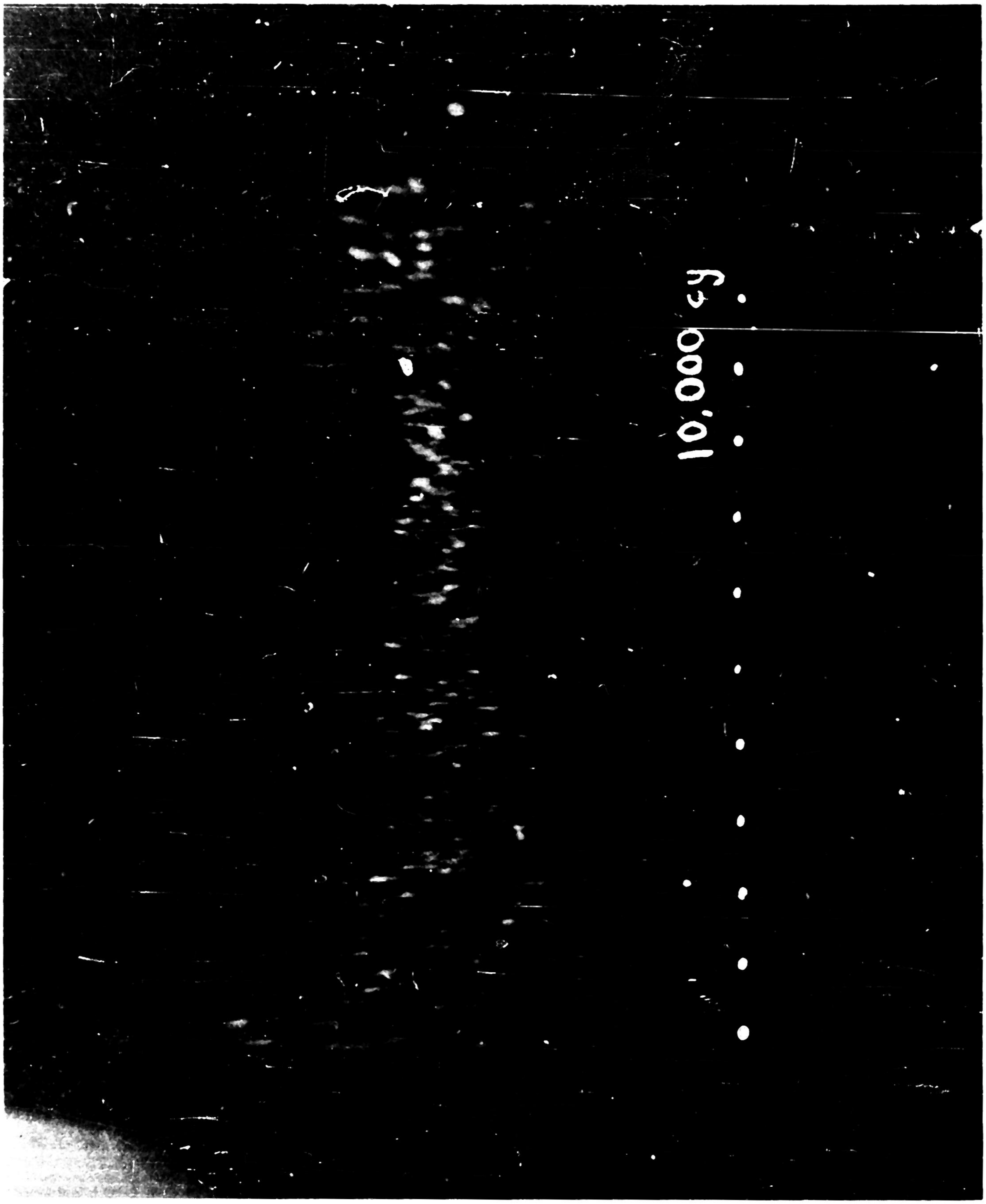

Figure 7a

Details of acoustic signal at impact of normal mine case. Dots are 100 microsecond markers.

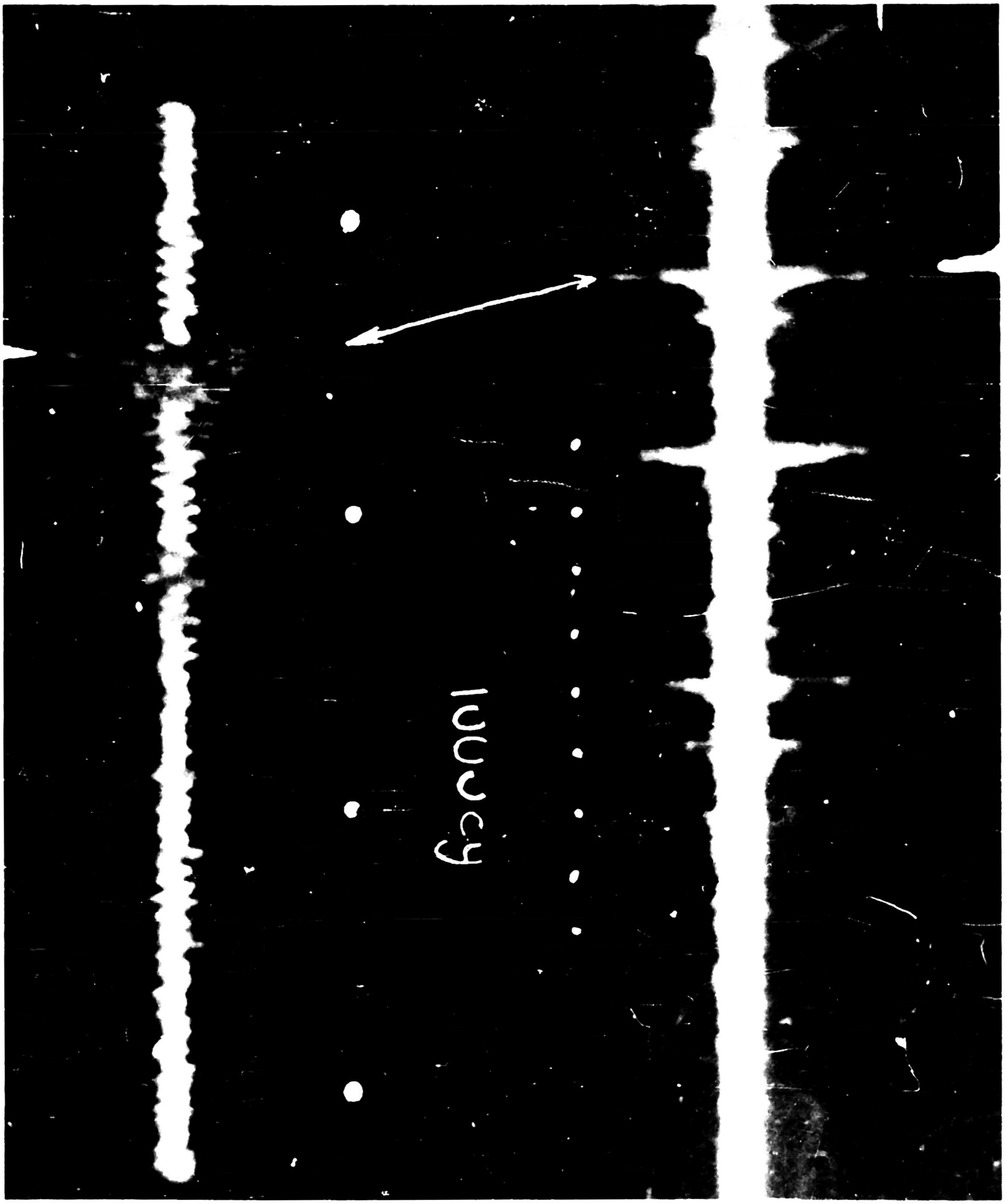

Figure 7b

Details of acoustic signal at slap of mine case against cavity wall. The arrows indicate the event recorded in the slower trace which has been expanded in the fast trace. Dots are millisecond markers.

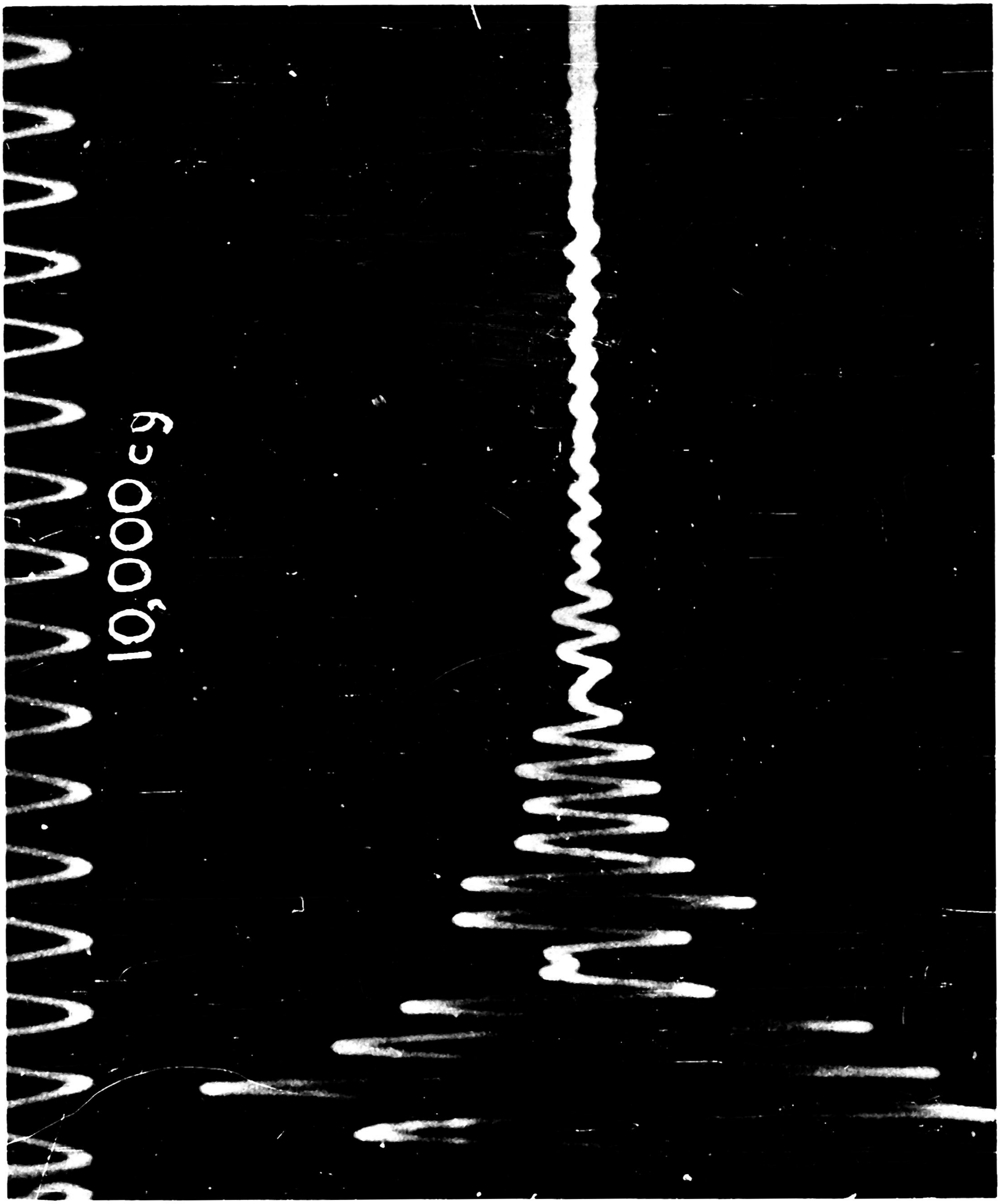

Figure 7c

Vibration of mine case when end is tapped in water to simulate entry impact.

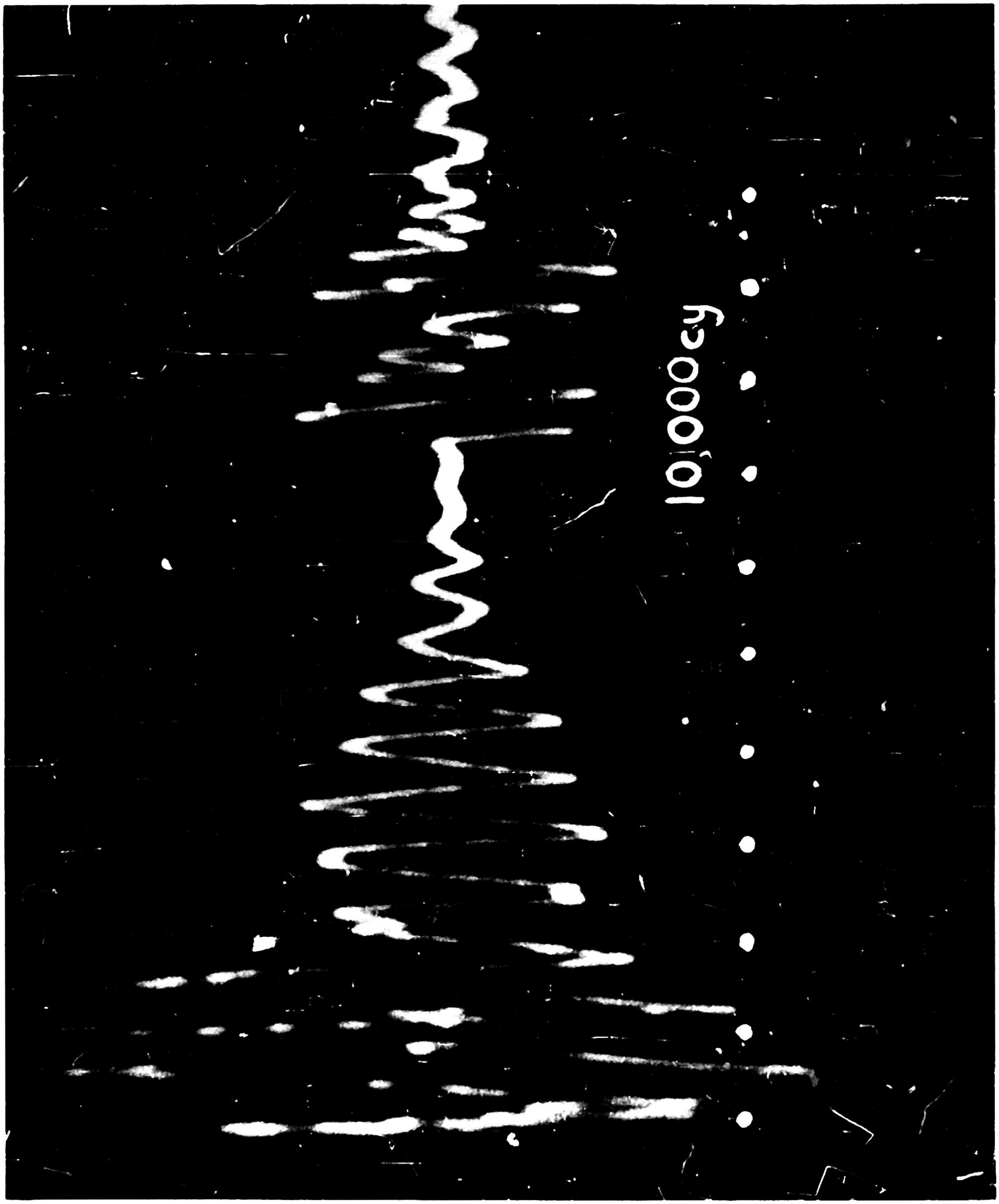

Figure 7d

Vibration of mine case when side is tapped in water to simulate broadside slap against cavity wall.

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